Laser Radar Ranging and Atmospheric Lidar Techniques II, Europto Proceedings Vol 3865, pp.76-82, Florence, Italy, Sept 20-21,1999.

"Engineering Progress on the Fully Automated, Photon-Counting SLR2000 Satellite Laser Ranging Station"

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1.0 INTRODUCTION

SLR2000 is an autonomous and eyesafe single photon-counting satellite laser ranging station with an expected single shot range precision of about one centimeter and a normal point precision better than 3 mm. The system will provide continuous 24 hour tracking coverage. Replication costs are expected to be roughly an order of magnitude less than that of current manned systems, and the system will be about 75% less expensive to operate and maintain relative to the current manned systems. Computer simulations have predicted a daylight tracking capability to GPS and lower satellites. Computer and hardware simulations have demonstrated the ability of our current correlation range receiver and autotracking algorithms to extract mean signal strengths as small as 0.0001 photoelectrons per pulse from solar background noise during daylight tracking.

The initial SLR2000 system concept was developed in 1994 [1], and the technical approach was refined in later years [2]. However, significant funding for the project was not provided by NASA until August 1997. During the first year of funding, prototypes of several "enabling" components, without which the system is not feasible, were successfully developed. These include: (1) a sensitive, high speed, quadrant microchannel plate photomultiplier; (2) a moderate power microlaser transmitter; (3) a "smart" meteorological station; (4) a high speed range gate generator; and (5) a high speed, high resolution event timer. Once the key specifications on these advanced components were largely met and system feasibility had been established, attention then turned to the detailed engineering design and procurement of more conventional elements of the system such as the shelter and protective dome, arcsecond precision tracking mount, telescope, and optical transceiver. The principal challenge during this second phase was to keep prototype fabrication and replication costs as low as possible to meet our cost goals.

Prototypes of the various SLR2000 components and subsystems have either been developed or are well into the detailed design/ build phase. The system is scheduled to conduct field tests in the 2000-2001 time frame. The primary driver for schedule is a fixed level of funding available each year to support SLR2000 development.

A fairly detailed engineering overview of the SLR2000 system was presented approximately one year ago at the 11th International Workshop on Laser Ranging in Deggendorf, Germany, and has recently been published in the Workshop Proceedings [3]. In addition, the SLR2000 project maintains a web site at the following URL address:

http://cddisa.gsfc.nasa.gov/920_3/slr2000/slr2000.html

Thus, only a brief overview of engineering status and a summary of recent developments (i.e. within the past year) on the various subsystems will be given here. The reader is referred to earlier publications [1-3] for more detail on the overall system.

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2.0 SYSTEM STATUS

2.1 Time and Frequency Reference

The purpose of the Time and Frequency Reference is twofold: (1) to provide accurate on-station epoch timing to simplify and accelerate the acquisition and tracking of the satellite targets; and (2) to provide an accurate frequency source for the pulse time-of-flight measurements. After testing several new commercial timing units, we selected the True Time Model LPFRS GPS-aided Rubidium oscillator and Model 151-358 GPS Synchronized Time and Frequency Receiver to serve as the prototype station clock and frequency reference for SLR2000. The unit uses timing information from the Global Positioning System (GPS) constellation of satellites to automatically constrain the long term frequency drift in a rubidium oscillator. During the past year, the unit was thoroughly tested in NASA's MOBLAS-7 satellite laser ranging station , where it ran simultaneously with the standard cesium reference and produced virtually identical range results.

2.2 Microlaser Transmitter

The frequency-doubled microlaser transmitter, operating in the visible at a wavelength of 532 nm and a repetition rate of 2 kHz, must produce approximately 130 μJ of energy at the telescope aperture. This is the maximum energy that can be passed through the 40 cm transmit/receive telescope at this repetition rate without exceeding the U.S. eye safety limit for Q-switched lasers. Because of anticipated losses in the optical train, the actual laser must produce about 220 μJ of green light at the source corresponding to about 440 mW of average power. The pulse width goal is 150 picoseconds or less.

A NASA-funded program at MIT Lincoln Laboratories produced a diode-pumped high power Nd: YAG microchip oscillator-only configuration which produced pulsewidths as short as 310 psec , pulse energies as high as 250 μJ, and average powers in excess of a Watt at 1064 nm and greater than 600 mW at 532 nm [4]. However, it was determined that this approach lacked flexibility in meeting conflicting microlaser specifications on pulsewidth, energy and repetition rate. Thus, the baseline design for the prototype transmitter is a diode-pumped, passively Q-switched, Nd:YAG microchip laser oscillator followed by a passive, CW diode-pumped multipass amplifier. NASA is attempting to develop a commercial source for this transmitter through a Phase II Small Business Innovative Research (SBIR) program at Q-peak Inc. in Concord, Massachusetts. To date, the company has generated up to 500 μJ per pulse at 1064 nm at rates up to 10 kHz (5 watts) in a microchip oscillator/passive multipass amplifier configuration although the pulsewidth goal of 150 psec has not yet been achieved. Delivery to NASA of the prototype SLR2000 laser transmitter is scheduled for March 2000.

2.3 Quadrant Microchannel Plate Photodetector

A quadrant microchannel plate photomultiplier was developed by Photek Ltd. in the United Kingdom under subcontract to AlliedSignal Technical Services Corporation (ATSC). This unique detector combines a fast risetime for precise ranging with a quadrant anode that allows pointing correction at the sub-arcsecond level in single photon counting mode [TBD]. Three prototype SLR2000 detectors were delivered in September-October 1998 and were tested by ATSC during the past year. One of these designs comes fairly close to meeting the original goals and will be used in the prototype SLR2000 system. Its demonstrated specifications are:

Quantum Efficiency: 13.60% @ 532 nm
S20 cathode
Bias Voltage: -4400 VDC
Rise Time: 179 -180 psec (all four quadrants)
Timing Offset Between Quadrants: < 8 psec

Timing Jitter: 39 - 47 psec (all four quadrants)
Gain: 3 x 10^6
External Gating: 3 nsec
Active Cathode: 8 mm diameter
Anode Structure: Quadrant, 4 square areas

2.4 Optical Transceiver

An early, but elusive, goal of the SLR2000 system was to develop a totally passive technique by which the full aperture of the primary could be shared by the transmitted and received beams with negligible optical loss. A variety of interesting approaches were examined and abandoned for various technical reasons [3], and we tentatively decided on an approach which was low loss but made use of two polarization-dependent receiver channels and an active electro-optic switch as in Figure 1. However, within the past two months, we have developed a novel, totally passive (i.e. has no electronic or mechanical parts), transmit/receive concept to accomplish this task; the new switch is implemented by replacing the electro-optic Q-switch in Figure 1 with a Faraday Isolator and half-wave plate. Both receiver channels feed into the Quadrant Micro-Channel Plate (QMCP) detector. This new "switch" can operate at arbitrarily high laser repetition rates, protects the transmitter from back reflections in the forward optics, and has low loss in either the transmit or receive mode even when interrogating depolarizing target satellites such as LAGEOS 1 and 2, which use uncoated Total Internal Reflection (TIR) retroreflector prisms.

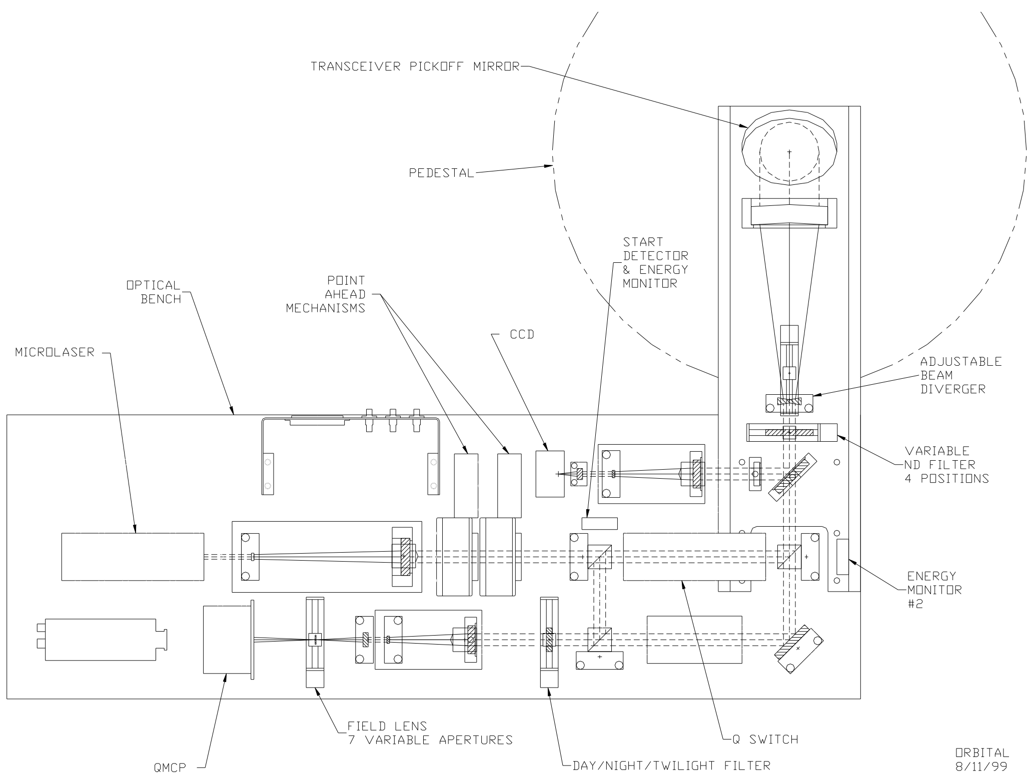

Figure 1: Optomechanical design of the transceiver. The active electro-optic Q-switch (Pockels Cell) has recently been replaced by a passive Faraday Isolator and Half-Wave Plate.

On the transmitter side, the microlaser beam is expanded by a ten power telescope and passes through two serial, stepper-motor driven Risley prisms which steer the beam slightly off the receiver axis to account for point-ahead on the satellite. The p-polarized beam passes through the input polarizer and is rotated to s-polarization by the Faraday Rotator/ half wave plate combination so that pulses reflect off the second (exit) polarizer. The beam divergence can be adjusted, based on satellite altitude, by a computer-controlled

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diverging lens in the intermediate telescope. The transmit beam can also be attenuated during ground target calibration via a computer-controlled Neutral density (ND) filter (which also attenuates the receive beam by the same amount).

On the receiver side, the exit polarizer splits the received photons into two channels based on polarization. The p-polarized photons pass through the exit polarizer, reflect off the 45 degree mirror, pass through a compensator block (which matches the s-channel time delay), and then pass through the final polarizing cube into the remainder of the receiver chain, which includes a narrowband filter, variable spatial filter, and quadrant detector. After reflecting off the exit polarizer, the s-polarized photons retrace the transmit path but, due to the non-reciprocal behavior of the Faraday Islator.half wave combination, retain their s-polarization and are reflected off the entrance polarizer and recombined with the p-polarized photons at the final (third) polarizing cube.

A CCD camera in a third leg of the transceiver aids in performing star calibrations and mechanical mount modeling in addition to maintaining system focus over a wide temperature range using the computer controlled diverging lens.

2.5 Ranging and Timing Electronics

The Correlation Range Receiver (CRR) must extract the weak signal return in the presence of a much stronger solar background and provide mm precision ranging at a 2 kHz rate. Two CRR's have been designed and tested. The first was constructed entirely from commercial nuclear timing components [2] and was shown to have a single shot noise floor of 4 mm RMS An enhanced version, based on an Event Timer built by ATSC for the Italian Space Agency's Matera Laser Ranging Observatory (MLRO) has a demonstrated timing precision of 5 psec RMS (< 1mm single shot range resolution) [3].

2.6 Telescope and Precision Tracking Mount

The contract for the arcsecond precision tracking mount was awarded to Xybion Corporation in Clearwater, Florida, in late August 1999 following a competitive bid. Delivery and acceptance testing of the prototype mount is scheduled for June 2000. The telescope and tracking mount are housed within an open dome during operations and hence are exposed to the ambient atmosphere. The optical path in the yoke arm of the mount is independently purged and sealed via O-rings to keep the path free of contaminants and atmospheric water vapor. Condensation control at the exit window of the telescope and at the telescope/yoke interface windows is accomplished via temperature and humidity sensors plus heater elements which raise the affected optical components a few degrees above ambient. Electrical connections for the sensors and heaters are provided via slip rings.

The prototype telescope uses a custom-designed 40 cm diameter off-axis all reflective telescope designed to operate over a wide temperature range (20 to 120^{o} F). The design (see Figure 2) incorporates various passive elements (invar rods, low expansion optical substrates, etc.) to maintain system alignment and focus over a wide temperature range but also allows for active control of the focus via a computer-translatable lens and CCD camera which can check the focus periodically by imaging stars [3]. The CCD camera is also used to perform periodic star calibrations to compensate for mechanical sag in the mount or telescope. The detailed opto-mechanical design is now largely complete. The telescope assembly is sealed independently of the tracking mount, and the interior is purged with dry air or nitrogen. Heaters on the input and exit windows of the telescope keep the surface a few degrees warmer than the ambient atmosphere to prevent condensation on the outer surfaces of the windows. Long lead optics have been ordered, and delivery of the telescope is expected in March 2000.

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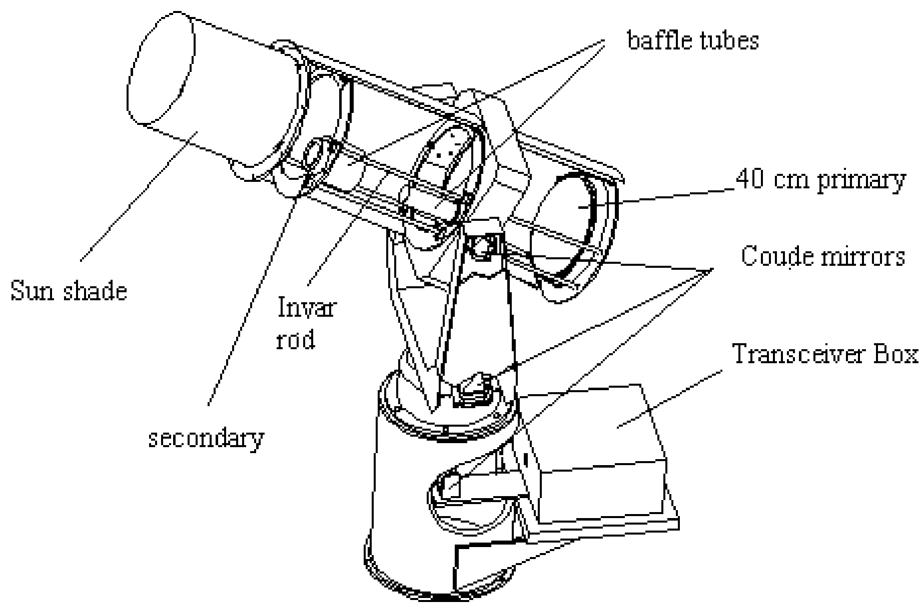

Figure 2: Cutaway view of the telescope, tracking mount pedestal, and transceiver box.

2.7 Meteorological Station

The "Smart" Meteorological Station measures surface pressure, temperature, relative humidity, wind speed and direction, ground visibility, type and accumulation of precipitation, and hemispherical cloud cover under both day and night conditions [3]. A Paroscientific MET3-1477-001 Pressure, Temperature, and Relative Humidity Monitor measures pressure, temperature, and relative humidity with the requisite accuracy for supporting atmospheric models used in applying the atmospheric correction in subcentimeter laser ranging. The Belfort 200 Wind Monitor measures wind speed and direction. The Vaisala FD12P Precipitation and Visibility Sensor monitors the presence, type, and accumulation of various forms of precipitation (rain, snow, etc.);as well as local visibility out to 50 Km. Finally, an Inframetrics Thermasnap™ camera, containing an uncooled silicon thermoelectric IR detector array operating between 8 and 12 microns, is placed above a convex mirror overcoated with gold in order to photograph the full sky cloud cover, day or night, nearly to the horizon in a single frame. Each pixel senses the temperature of the sky within its field of view. Low lying cumulus cloud temperatures tend to follow the lapse rate with altitude and hence are at significantly higher temperatures (10-20^{o}C) than the higher cirrus or clear sky backgrounds. The resulting “cloud mask”, combined with the wind, visibility, and precipitation sensors, assists the software “pseudo-operator” in deciding whether or not to open the observatory dome and begin, continue, or end laser operations. Based on cloud distribution, the “pseudo-operator” can also decide which satellites to track and over what portions of the orbit.

2.8 Real-Time Controller and Software

The SLR2000 controller consists of three Pentium-based processors, two UNIX-based processors in a VME backplane and the third in a PC/ISA crate. The VME bus was chosen for its higher bus speed (40MB/sec), while the ISA bus was needed to handle specialized interface cards for key components. The ISA computer functions as an Input/Output processor, passing data to and from the VME computers via shared memory. The VME processors perform all of the decision making, data analysis, and external communication. One of these processors, the "Pseudo-Operator (POP)", performs the functions of a human operator, making decisions on whether the weather permits opening the dome and tracking, which satellite

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should be tracked, and whether the returns in the ranging window are signal or noise. The Pseudo-Operator also acts to protect the system if it detects system health or safety problems. The second VME processor, called the "Data And Analysis (DAN)" CPU, processes and exchanges range and orbit prediction data with the central network archive. Human interaction with the SLR2000 system requires communicating with the Analysis CPU through the internet. A laptop PC, the "Remote Access Terminal (RAT)", running a special software package will allow onsite maintenance personnel to monitor the operation of the system via graphical displays, get information from the system to analyze off-line, run diagnostic tests, and change system parameters. The computer subsystem and software packages are described in detail elsewhere [5-8].

2.9 Environmental Shelter and Dome

The SLR2000 system is protected by the environmental shelter and azimuth tracking dome illustrated in Figure 3. The facility sits on a stable concrete pad. The walls, roof, and floor of the shelter are assembled from prefabricated sheets manufactured by the Bally Corporation and are typically used in building refrigeration boxes. Each wall panel is 10 cm thick and consists of thermally insulating material sandwiched between two aluminum outer surfaces which can be painted or otherwise treated to withstand harsh environments. Besides their excellent insulation and durability, the panels provide a relatively dust free environment and are easy to assemble onsite via interlocking connectors. The 3 meter diameter fiberglass dome, manufactured by Technology Innovations Inc., has a motorized open slit (shutter) and azimuth drive. Both are under computer control and the dome azimuth drive is slaved to the tracking mount azimuth. The electronics room is thermally isolated from the open dome area by a removable ceiling is and maintained at a nominal 23^{o}C by a dual heater/air conditioning system for low operating loads and redundancy. This stabilizes the temperature of critical elements in the optical transceiver and timing electronics and provides a comfortable workplace for visiting maintenance personnel.

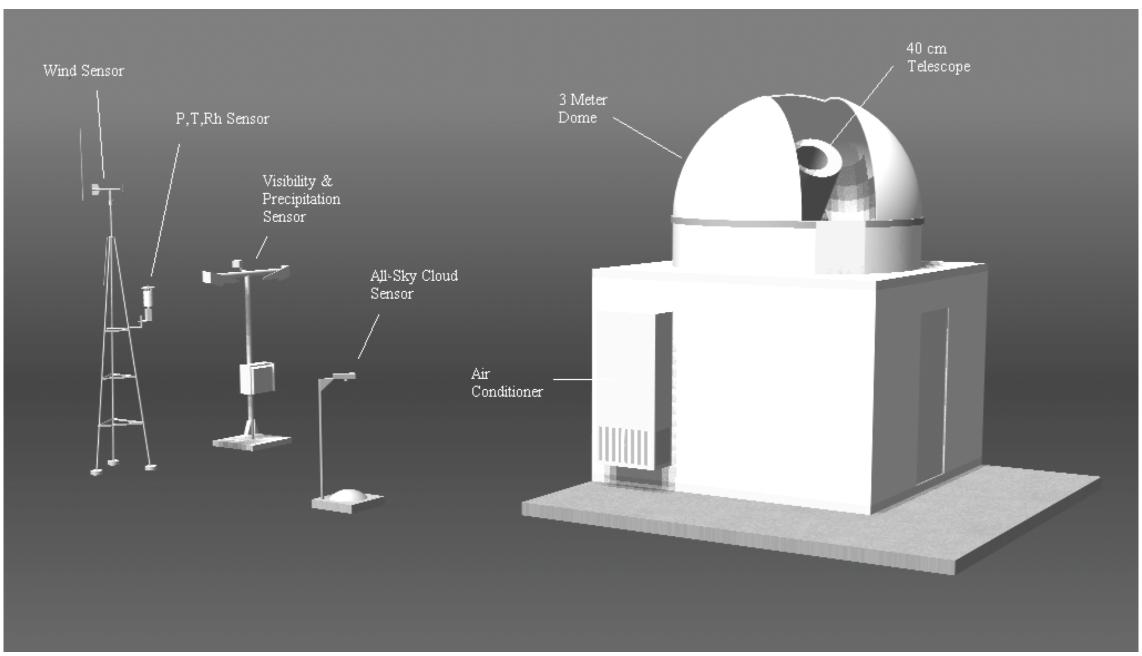

Figure 3: Three-dimensional CAD/CAM drawing of SLR2000 station and meteorological subsystem.

Outside ambient air and heated air from the electronics room are dehumidified and mixed to maintain the telescope slightly above ambient when the dome is closed in order to minimize thermal gradients and prevent water condensation upon opening the dome. Inexpensive security devices automatically detect, record, and report threats to system security via Internet and/or recorded telephone messages. These include motion and intrusion sensors and surveillance cameras for detecting and reporting unauthorized personnel in the vicinity, thermal sensors for detecting heat pump failure, power/voltage monitors, etc. Key security components, such as the computer and selected sensors, are protected by UPS, and the safe default mode for key subsystems will be "Power Off" in the event of a power failure. The prototype shelter is currently being fabricated.

3.0 CONCLUDING REMARKS

The development schedule for SLR2000 is presently being driven by the fixed funds available each year for the program. During the current fiscal year, we are concentrating on the development, fabrication, and test of the shelter, tracking mount, and telescope while continuing other engineering and software development at a somewhat reduced level relative to last year. Because of these financial restrictions, completion and full field testing of the overall satellite laser ranging system cannot be completed before 2001.

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